RADIATION PHYSICS NOTE 54

A STUDY OF NEUTRON TRACK FADING IN NTA FILM DOSIMETERS

Jack G. Couch and W. Charles Salsbury

May 1985

Introduction

Health physicists have long been aware that proton recoil tracks formed by neutron exposure in emulsions such as Kodak's nuclear film type A (NTA) fade with time. The presence of oxygen plays the principal role in track fading. Silver atoms formed by ionizing radiation are reoxidized to silver ions by the chemical process

$$2Ag + O + H_2O \rightarrow 2\ Ag^+ + 2OH^-.$$

Fading is enhanced by high temperatures and humidities.

Other constraints that must be addressed if NTA emulsions are to be of use in personnel neutron dosimetry include energy threshold limitations and interference from associated photon irradiation. The recent article by Höfert and Piesch (Ref. 1) contains a good review of the principles and limitations of using NTA film including a study of the fading process.

The purpose of the present study has been to confirm and document suspected neutron fading in P1 NTA film badges (Ref. 2) used at Fermilab.

Experimental Procedure

Film badges used in this study were exposed to the Neutron Therapy Facility (NTF) fast neutron beam which has a maximum energy of 66 MeV. Ref. 3 shows the neutron energy spectrum. This neutron beam was chosen because it provides high neutron dose rates at high energies with minimal photon contamination. A 24x24 cm beam collimator was used in order to provide a reasonably uniform beam over the area covered by the film badges. All irradiations were done at a programmed dose setting of 0.03 jig Gy. Ref. 4 describes details of the NTF and its operation. There is no simple method of relating NTF programmed settings to neutron dose or dose equivalent in air. Also, the vendor's calibration is likely not correct for the neutron spectrum of this beam. Therefore, all neutron dose equivalent readings in this study must be regarded as relative.

First, three sets of six badges, all of the same wear date, were irradiated separately at the same dose setting and sent to the vendor for immediate reading. This was done in order to assess the beam reproduceability and to evaluate the scatter in neutron readings provided by the vendor.

On February 25, 1985 the set of 25 badges used in the fading study was irradiated. These badges were from two different wear periods. Six films were sent immediately for reading, then three or four films from the set were sent at intervals of approximately one week. Each set contained badges of both wear periods.

We also irradiated stacks of NTA film in the NTF beam to explore buildup effects. For this we used three stacks of three films each (without badge holders) backed by a block of polyethylene. All these films were sent to the vendor for reading at the same time.

Experimental Results and Analysis

The results of the first three sets of badge irradiations are shown in Table 1. The standard deviations for each set, which averaged about $\pm$ 9%, indicate that consistency by the vendor in assigning doses is reasonably good. The mean dose for one of the three irradiations is about 35% lower than the others. This shows that exposures cannot be reproduced reliably for separate irradiations at these very low beam exposure settings. It was for this reason that we chose to irradiate all films used in the fading test simultaneously. Gamma doses are low and consequently do not interfere with neutron readings in this study.

The results of the 25 badges used for the fading test are listed in Table 2. The number of days from exposure to reading had to be estimated by adding 3($\pm$1) days to the date each set was sent for reading. Averages and standard deviations for the two wear periods and for the composites are shown at the bottom of the table.

There may be an effect on fading due to the one month difference in wear period. However, the sizeable errors prevent any firm conclusions on this point.

In Figure 1, the averages of the Table 2 readings are plotted versus storage time between exposure and reading. A best-fit straight line, extrapolated to the exposure time ($t = 0$), is included. The results were replotted in Figure 2 as the percent of the intercept ($t = o$) of the best-fit line.

The badge readings decreased by about 60% of the extrapolated initial reading in 30 days and by about 85% in 45 days.

Similar data from Reference 1 is represented as a dashed line in Figure 2. We have normalized their extrapolated data to 100% in order to compare their results with ours. Their films were dried and sealed before use, then maintained at 20°C and 20% relative humidity. Their measurements showed 50% fading within three days, then the data followed the dashed, straight line consistently for over 12 weeks. Their readings decreased 25% from the extrapolated intercept in 30 days compared to our 60%.

We attribute the more rapid fading of our film to the fact that we made no attempt to control film environment.

The data for the irradiated stacks of film are listed along with averages and errors in Table 3. The difference in dose for the three film layers is attributed to proton recoil track buildup at increased depths. Clearly, the buildup is rapid. The reading increased by approximately a factor of two from the first to the third film.

This suggests some interesting questions that might be worth exploring in future studies. For example, what error is introduced in the neutron film reading due to track buildup or attenuation if the neutrons are incident from the back of the badge holder rather than the front?

Discussion

Our data serve to confirm that neutron track fading is a serious problem if special steps are not taken. Based on our data, neutron dose equivalents of several hundred mrem easily could go undetected under normal time delays of 30-45 days between exposure and reading.

As with many radiation measuring devices, if the spectra of the calibration beam and the neutron field to which the NTA film is exposed are different, the error in calibration can be large. This is illustrated dramatically in Figure 3. The neutron spectrum shown was measured in the second leg of a neutrino beamline personnel access labyrinth. (Ref. 5). The approximate range of energy sensitivity of NTA film is shown as the horizontal bar. Not only are the neutron spectra of the vendor's calibration source and the labyrinth neutron vastly different, virtually all of the labyrinth neutrons have energies well below the 0.5 MeV threshold energy of the film.

As an added complication, attempts made at the time to measure neutron dose with NTA film proved nearly hopeless because of high photon dose rates. On this last point, Höfert (Ref. 1) showed that problems with counting proton recoil tracks are encountered if the NTA film is exposed to more than 1 rem gamma or 0.5 rem soft x-radiation.

Summary and Conclusions

NTA film badges were exposed to the NTF fast neutron beam and tested for fading. The results showed 60% fading in 30 days and 85% fading in 45 days.

NTA film was shown to be virtually insensitive to neutrons in one case where a strong neutron field existed. Interference by the associated high photon radiation level would probably have prevented measurement of neutrons at that location in any case.

We conclude that because of track fading and other constraints, the usefulness of NTA film as a personnel neutron dosimeter is limited. However, NTA film may still be useful as a detector in providing information about the presence, absence or relative fluence of neutrons.

Acknowledgement

The authors wish to thank W. Freeman for reviewing this report and for offering several valuable suggestions.

<u>References</u>

1. Höfert, M., and Piesch, E., "Neutron Dosimetry with Nuclear Emulsions". Radiation Protection Dosimetry, Vol. 10, No. 1-4, pp. 189-195 (1985).

2. P1 NTA badges supplied by R. S. Landauer, Jr. and Company, Glenwood Science Park, Glenwood, Illinois 60425.

3. Ten Haken, R.K., Awschalom, M., and Rosenberg, I., "Activation of the Major Constituents of Tissue and Air by a Fast Neutron Radiation Therapy Beam". Medical Physics, Vol. 10, No. 5, pp 636-641 (1983).

4. Awschalom, M., and Rosenberg, I., "Fermilab Cancer Therapy Facility Neutron Beam Calibration and Treatment Planning". Fermilab TM-834 (1978).

5. Cossairt, J.D., Couch, J.G., Elwyn, A.J., and Freeman, W.S., "Radiation Measurements in a Labyrinth Penetration at a High Energy Proton Accelerator", Fermilab FN-406 (submitted to Health Physics), July 1984.

TABLE 1 NTA FILM EXPOSURE TESTS

Group 1	γ(mrem)	n(mrem)
	10	5470
	10	5170
	10	4750
	20	5380
	20	4530
	20	5590
Mean		5148 ± 423 (8.2%)

Group 2	γ(mrem)	n(mrem)
	30	8420
	40	8580
	40	8210
	30	7050
	40	8090
	40	6790
Mean		7857 ± 749 (9.5%)

Group 3	γ(mrem)	n(mrem)
	40	9170
	40	7930
	30	7490
	40	8390
	40	6890
	40	8120
Mean		7998 ± 779 (9.1%)

TABLE 2 NEUTRON FADING DATA

Film #	Wearing Date	Return Date	Reading (mrem) Neutron	# of Days From Exposure To Reading
60305	1/85	2/26/85	3390	4
60308	1/85	2/26/85	3600	4
60311	1/85	2/26/85	4720	4
60816	2/85	2/26/85	4130	4
60821	2/85	2/26/85	4820	4
60824	2/85	2/26/85	4266	4
60304	1/85	3/6/85	4490	12
60306	1/85	3/6/85	4350	12
60819	2/85	3/6/85	3810	12
60820	2/85	3/6/85	4180	12
60303	1/85	3/11/85	2240	17
60313	1/85	3/11/85	2890	17
60822	2/85	3/11/85	3440	17
60823	2/85	3/11/85	3440	17
60302	1/85	3/18/85	1650	24
60309	1/85	3/18/85	2250	24
60817	2/85	3/18/85	2300	24
60818	2/85	3/18/85	2840	24
60301	1/85	3/25/85	1560	31
60312	1/85	3/25/85	1500	31
60814	2/85	3/25/85	2870	31
60815	2/85	3/25/85	2080	31
60307	1/85	4/1/85	1260	38
60310	1/85	4/1/85	1170	38
60825	2/85	4/1/85	1280	38

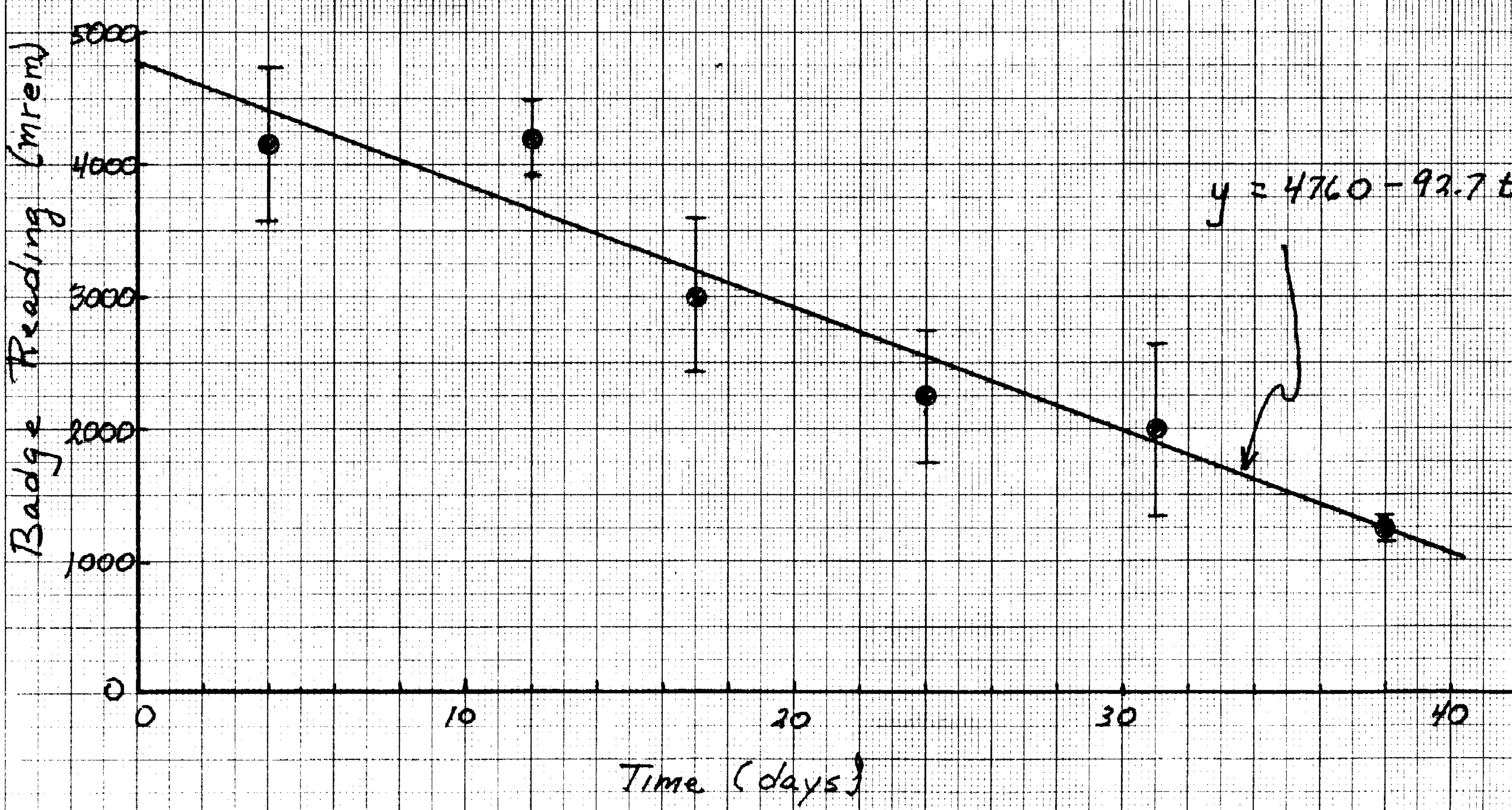
RETURN DATE	JAN. BADGES AVERAGE	FEB. BADGES AVERAGE	BOTH AVERAGE
26 Feb.	3903 ± 715	4405 ± 365	4154 ± 578
6 March	4420 ± 99	3995 ± 262	4208 ± 294
11 March	2565 ± 460	3440 ± 0	3003 ± 571
18 March	1950 ± 424	2570 ± 382	2260 ± 487
25 March	1530 ± 42	2475 ± 559	2003 ± 634
1 April	1215 ± 64	1280 ± 0	1237 ± 59

TABLE 3 STACKED NTA FILM

BADGE #	NEUTRON DOSE (mREM)	AVERAGE
		Top Badge
60279	3080	
60276	2830	
60274	3030	
		2980±132
		Middle Badge
60280	3690	
60277	3240	
60282	4310	
		3747±537
		Bottom Badge
60281	5250	
60278	5030	
60275	6400	
		5560±736

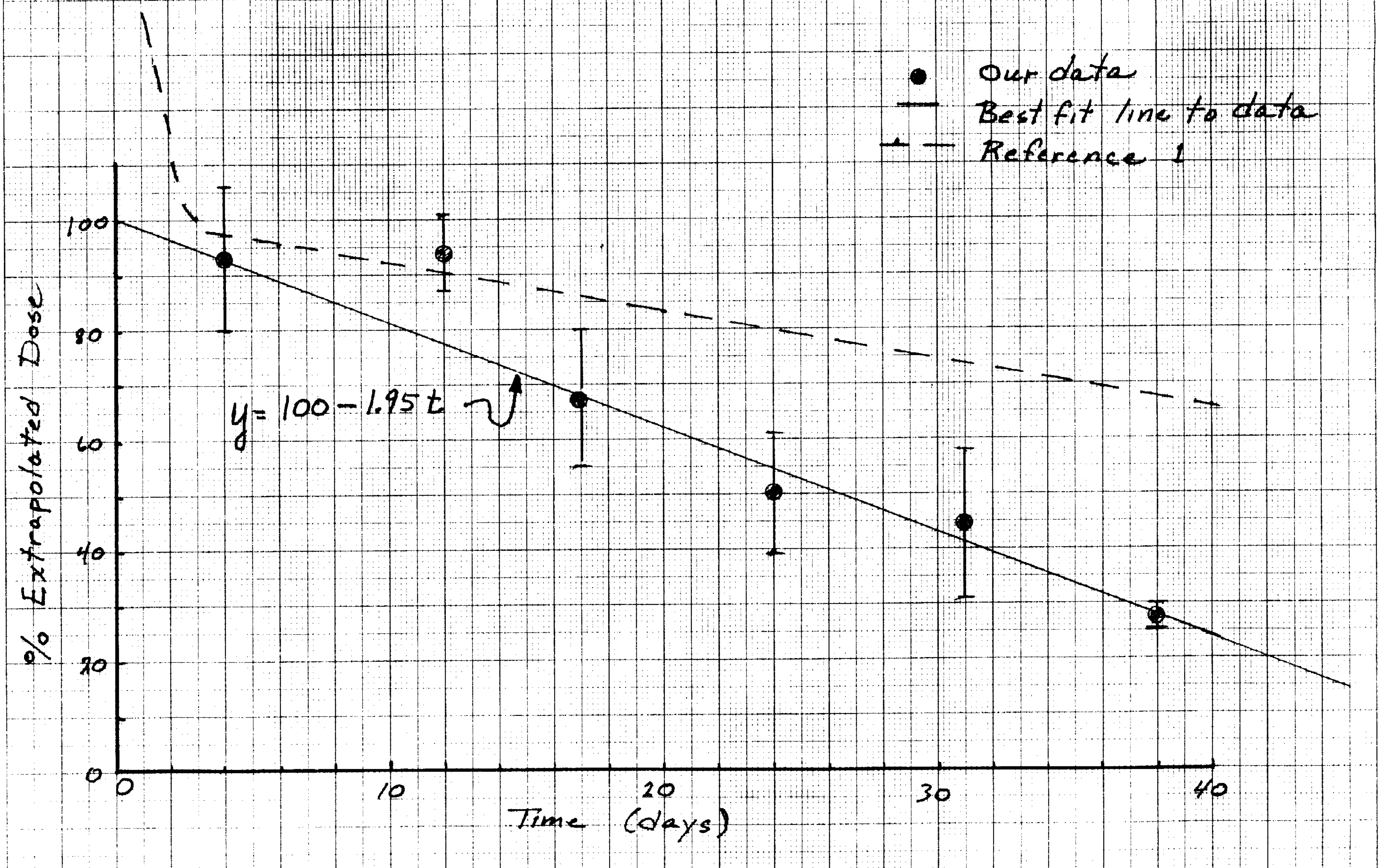
Figure 1

FILM BADGE READING
VS
STORAGE TIME AFTER IRRADIATION



461510

Figure 2 FADING VS STORAGE TIME AFTER IRRADIATION



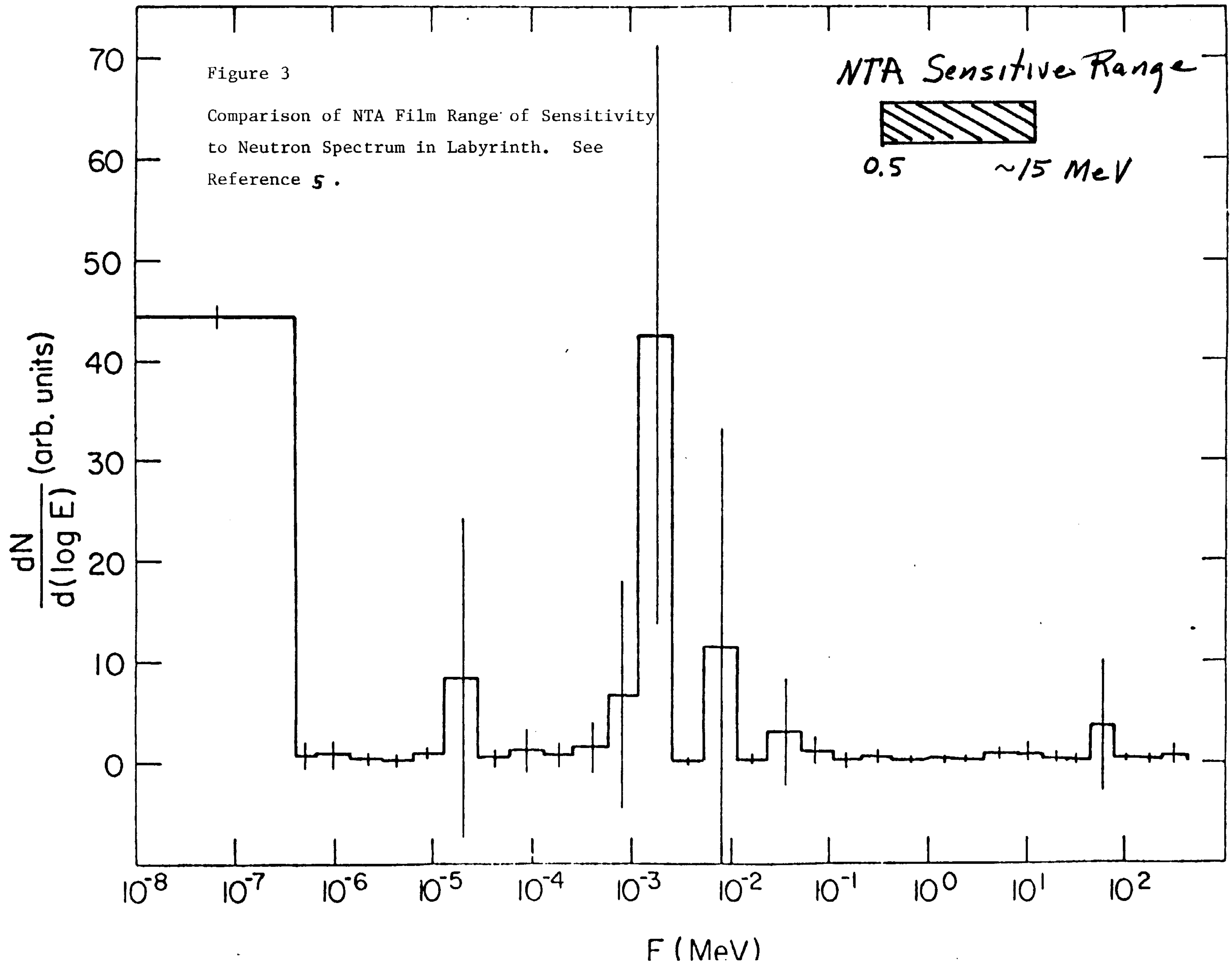


Figure 3

Comparison of NTA Film Range of Sensitivity to Neutron Spectrum in Labyrinth. See Reference 5.